

2013

## Virtual swimming - breaststroke body movements facilitate vection

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### Recommended Citation

Seno, Takeharu; Funatsu, Fumiya; and Palmisano, Stephen, "Virtual swimming - breaststroke body movements facilitate vection" (2013). *Faculty of Social Sciences - Papers*. 271.  
<https://ro.uow.edu.au/sspapers/271>

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### Abstract

Visually induced illusory self-motion (vection) was facilitated by active breaststroke arm and body movements. Optic flow was generated by having the standing observer make these arm movements, which were detected by Kinect and incorporated into the display. When generated, this optic flow was either expanding (i.e. congruent with the observer's head motion) or contracting (i.e. incongruent with his/her head motion). Optic flow generated during these active movement conditions was also later played back to the observer during passive viewing conditions. On each of these trials, we recorded vection strength (latency, duration and magnitude). We found that: (i) both congruent and incongruent breaststroke movements increased vection (i.e. compared to passive viewing conditions); and (ii) congruent breaststroke movements increased vection more than incongruent ones. We name the enhancement provided by this type of active movement 'virtual swimming'. This demonstration shows that even unusual body movements can function as a self-motion signal.

### Keywords

facilitate, vection, swimming, virtual, breast, stroke, body, movements

### Disciplines

Education | Social and Behavioral Sciences

### Publication Details

Seno, T., Funatsu, F. & Palmisano, S. (2013). Virtual swimming - breaststroke body movements facilitate vection. *Multisensory Research*, 26 (3), 267-275.

## **Virtual swimming**

### **- breaststroke body movements facilitatevection -**

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## **Abstract**

**Visually induced illusory self-motion (vection) was facilitated by active breaststroke arm and body movements. Optic flow was generated by having the standing observer make these arm movements, which were detected by Kinect and incorporated into the display. When generated this optic flow was either expanding (i.e. congruent with the observer's head motion) or contracting (i.e. incongruent with his/her head motion). Optic flow generated during these active movement conditions was also later played back to the observer during passive viewing conditions. On each of these trials, we recorded vection strength (latency, duration and magnitude). We found that: (i) both congruent and incongruent breaststroke movements increased vection (i.e. compared to passive viewing conditions); and (ii) congruent breaststroke movements increased vection more than incongruent ones. We name the enhancement provided by this type of active movement "Virtual swimming". This demonstration shows that even unusual body movements can function as a self-motion signal.**

Multiple sensory modalities contribute to the perception of self-motion (Gibson, 1966), with their inputs generally being integrated (Rieser et al., 1995). However, illusory self-motion perception (known as 'vection') can be generated by visual stimulation alone. A number of studies suggest that visually induced self-motion is facilitated by congruent information from the other self-motion senses. Firstly, Ash et al (2011) have reported that congruent active head movements increase the vection induced by optic flow. Similarly, Seno et al (2011a) found that congruent locomotion on a treadmill increased vection, whereas incongruent locomotion inhibited it. Vection can also be increased by the physical motion of sound sources around a stationary observer while viewing a congruent vection stimulus (Riecke et al 2009). Finally, adding congruent somatosensory cues directly to the observer's hand or as the result of air-flow to the observer's face has also been shown to increase vection (Lécuyer et al, 2004; Seno et al., 2011b).

When information from the different self-motion senses is incongruent, the brain may engage in sensory recalibration in order to minimise the conflict. Previous research by Harris, Morgan and Still (1981) found empirical support for this notion. They proposed that motion aftereffects (i.e. the illusory motion of a physically stationary scene following exposure to visual movement) are evidence of sensory recalibration. In their study, participants viewed displays simulating self-motion in depth while stationary or seated on a trolley that moved with the display. They predicted that if the brain recalibrates during sensory conflict then the former incongruent condition should produce larger motion aftereffects than the latter congruent condition. Consistent with their proposal, they found that visual motion aftereffects were significantly greater in the incongruent condition.

This story is, however, complicated by several recent findings which appear to show thatvection is also enhanced by incongruent physical self-motions (relative to conditions in which subjects engage in no physical motion). For example, Kim and Palmisano (2010) reported that incongruent active head movements (180° out-of-phase with the display motion) increasedvection in a very similar fashion to congruent active head movements (in-phase with the display motion) (this finding is related to the facilitation ofvection in depth by visually simulated viewpoint jitter and oscillation, see Palmisano et al., 2011). Similarly, Onimaru et al (2010) also reported thatvection was still increased when the directions of the visually simulated self-motion and the observer's locomotion on a treadmill were incongruent.

Thus the aim of this study was to further examine the effects of non-visual self-motion stimulation onvection. There were both 'active movement' and 'passive viewing' conditions. In the active movement conditions, subjects made breaststroke hand and arm movements during the visual stimulus presentation (these also resulted in movements of the head and upper torso as well). In the 'active congruent' condition, these tracked breaststroke movements generated radially expanding optic flow, whereas in the 'active incongruent' condition, these tracked breaststroke movements generated radially contracting optic flow. We recorded movies of the expanding/contracting optic flow generated by these breaststroke motions and later, in the passive viewing trials, we presented these movies again to the subjects while they stood still.

We are typically much less familiar with swimming than walking. In addition to this, the ‘virtual swimming’ in our study was quite different from real breaststroke. Not only did this ‘virtual swimming’ involve swimming without water, but observer’s orientation (with respect to both gravity and the simulated direction of travel) and body movements were also different. Thus, it was unknown whether the active breaststroke body movements would increase vection (even when they were congruent with the motion of the optic flow display). On the one hand, if only the perceived validity of the body movement relative to the optic flow was important, then these virtual swimming motions might be sufficient to modulate vection. On the other hand, if the learnt correspondence between the type of optic flow and the type of body movement was important, then natural/common body movements might be necessary to modulate vection.

All the stimuli were created using “Processing-language” (<http://processing.org/>) based on Java. These optic flow displays subtended a visual angle of 72° (horizontal) x 57° (vertical) from the viewing distance 70 cm. They were generated and controlled by a computer (Apple, MB543J/A). The stimuli were presented on a plasma display (3D VIERA, 50 inches; Panasonic) with a 1,024 x 768 pixel resolution at a 60-Hz refresh rate. The experiments were conducted in a darkened room. The radially expanding or contracting optic flow was presented for 20 seconds. These self-motion displays were created by positioning 16,000 dots at random inside a simulated cube (length 20 m), and updating the subject’s simulated viewpoint in the display based on their physical breaststroke body movements. These body movements were detected using the Kinect (Microsoft) and were then converted into visual display motions (as can be seen in the demo movies). Kinect detects the positions of the subject’s hands, wrists, elbows and shoulders. By analyzing those positional changes, the whole breaststroke motion was detected/estimated. The threshold of those positional changes was modulated based on subject feedback – the aim being to maximise the feeling of virtual swimming (This was achieved by modulating the scaling factor rather than changing the subject’s body movement). The simulated speed of self-motion in depth ranged from 0 (Minimum) to 16 (Maximum) m/sec in the simulated space (see demo movie). As dots disappeared off

the edge of the screen, they were replaced at the far depth plane (thereby creating an endless optic flow display). Approximately 1,240 dots were presented in each frame, and each dot subtended a visual angle of  $0.03^{\circ}$ – $0.05^{\circ}$  (While the physical size of the dot on the screen was constant, egocentric distances to the different dots varied because the screen was so large). The sizes of these dots remained constant as their simulated distances changed. The visual stimuli were the flat patterns on 2D screen.

The experiment had a 2 (active/passive) x 2 (congruent/incongruent) design. In the passive conditions, the stimuli were playbacks of the movies of expanding or contraction optic flow generated by the observers' own body movements in the earlier active conditions. We measured the latency and durations of the forward or backward vection for each of the four conditions. Subjects were instructed to press a button (Wii controller, Nintendo) when they perceived self-motion. We also ensured that the subjects were given sufficient practice in pressing the button and doing the breaststroke movements before they started the actual experimental trials. At the end of each trial, they were instructed to rate the subjective strength of vection via a modified version of magnitude estimation. They were told that their estimated values should range from 0 (no vection) to 100 (very strong vection). While we did not use a standard stimulus for this magnitude estimation, we have used this exact method successfully in several previous studies (e.g., Seno et al. 2009, 2010, 2011 and 2012). The instructions were as follows: 'Please press the corresponding button while you are perceiving self-motion. If such a decision becomes difficult, or if self-motion perception disappears, please release the button.' We were careful not to give subjects any suggestions about our hypotheses because vection can be modulated by instructions/cognitive bias (e.g., Lepecq et al. 1995; Palmisano and Chan, 2004). Subjects practiced pressing the button while viewing a radial optic flow stimulus before starting the experiment.

The subjects comprised twelve adult volunteers. They were graduate or undergraduate students (aged between 20 and 25 y; six males and six females). They all had normal vision and healthy vestibular systems. None of the subjects were aware of the purpose of the experiment. The subjects had previously perceived normal vection (either when standing or sitting with their arms motionless) using the same apparatus. In terms of their swimming backgrounds, there was a range of experience. While nine of our

subjects were able to swim breaststroke, three reported that they were not able to swim at all. Six subjects out of nine subjects who could swim had been formally taught to swim breast-stroke in a swimming school/club by professional coaches (lesson durations ranged from at least one month to at most three years). The other three were less experienced swimmers, learning to swim from their parents and in elementary school when they were children.

In the main experiment, the passive conditions were always conducted after the active conditions. However, an additional control experiment conducted on 4 additional naïve subjects confirmed that time/trial order had little/no effect on vection – with later active conditions producing similar vection to earlier active conditions. The congruent and incongruent conditions were counter balanced over all subjects. Each condition was repeated four times.

Two-way analysis of variance revealed significant main effects of viewing type (active, passive) on vection duration ( $F(1,12) = 5.29$ ,  $P < 0.05$ ; magnitude) and vection magnitude ( $F(1,11) = 18.68$ ,  $P < 0.01$ ). However, the main effect of viewing type failed to reach significance for vection latency ( $F(1,12) = 3.44$ ,  $P < 0.1$ ). Specifically, vection latencies, durations and magnitudes were shorter, longer and larger in the active movement conditions than in the passive viewing conditions. By contrast, the main effect of congruency (congruent, incongruent) was only significant for the vection duration data - not for vection latency and magnitude (latency,  $F(1,11) = 2.40$ ,  $P > 0.05$ ; duration  $F(1,11) = 5.16$ ,  $P < 0.05$ ; magnitude,  $F(1,11) = 2.38$ ,  $P > 0.05$ ). However, we did find significant 2-way interactions between viewing type and congruency for all three vection measures (latency,  $F(1,11) = 6.85$ ,  $P < 0.05$ ; duration  $F(1,11) = 8.11$ ,  $P < 0.05$ ; magnitude,  $F(1,11) = 5.94$ ,  $P < 0.05$ ). These findings were interpreted as follows: (i) the differences between the active and passive conditions were larger in the congruent conditions than in the incongruent conditions; and (ii) while vection was increased by active breaststroke movements both in congruent and incongruent conditions (relative to passive viewing conditions), the degree of facilitation was larger in congruent condition.

Recently, Ash et al (2011) found that vection in depth could be increased by subjects actively moving their heads from left-and-right while viewing radial flow. Consistent with the findings of the current experiment, congruent (in-phase) horizontal head-and-display movements increased vection more than incongruent (180° out-of-phase) horizontal head-and-display movements. However, when the subjects made fore-and-aft head movements, both congruent and incongruent head-and-display movements increased vection in a similar fashion. As in the Ash et al study, head position data was also recorded in the current study. These data confirmed that: (i) the subject's head position did oscillate back and forth when they made breaststroke arm motions; and (ii) these head position changes were very similar in congruent and incongruent conditions. Thus, Ash et al's depth axis findings appear inconsistent with our finding that congruent fore-and-aft head motion increases vection. We conclude that the extra hand and arm motions in our active breaststroke conditions were likely to have been responsible for this congruent vection advantage. We plan to examine this explanation in future experiments.

In several previous studies (e.g. Bubka et al, 2008; Trutioiu et al. 2009), the backward vection induced by radially contracting flow has been more compelling than the forward vection induced by radially expanding flow (when all other factors were held constant). We did not obtain such a backward vection advantage in passive viewing conditions of the current experiment. However, several other studies have also failed to find this effect (Nakamura and Shimojo, 1998; Palmisano et al, 2009). It is possible that the current failure to generate a backwards vection advantage was related to the speed profile of our stimuli. The speeds simulated by both our contracting and expanding displays were not constant – they alternated between visually simulated self-motion and no display motion. As a result, the vection obtained in both our expanding and contracting passive viewing conditions was rather weak.

This virtual reality experiment clearly shows that unusual/atypical body movements are capable of modulating vection. Furthermore, even when the body movement is unusual/atypical, there still is an effect of stimulus-body movement congruency – with congruent body movements increasing vection more than incongruent body movements. Experience swimming breast-stroke may have contributed to performance. For two of

the three subjects who could not swim, vection did not appear to be facilitated by congruent breaststroke body movements. This observation suggests that if one has minimal swimming experience, then breaststroke arm movements may provide little or even no vection facilitation. While this possibility is intriguing, the number of subjects who could not swim was small in the current study. It was also possible that the effects of making congruent/incongruent breaststroke body movements on vection may have been more extreme if body posture tested was closer to that typically adopted when swimming breaststroke. Both swimming experience and subject posture during testing should therefore be the focus of future research.

Here we have shown that congruent breaststroke movements increase vection more than incongruent breaststroke movements. There is evidence that this congruency between the visual and other modalities' inputs is determined perceptually. For example, Seno et al. (in press) reported that perceptually congruent sounds facilitate vection - with upwards vection increasing as the pitch of the sound increases (and visa versa). Thus, it appears that links between multiple modalities may be determined perceptually for self-motion.

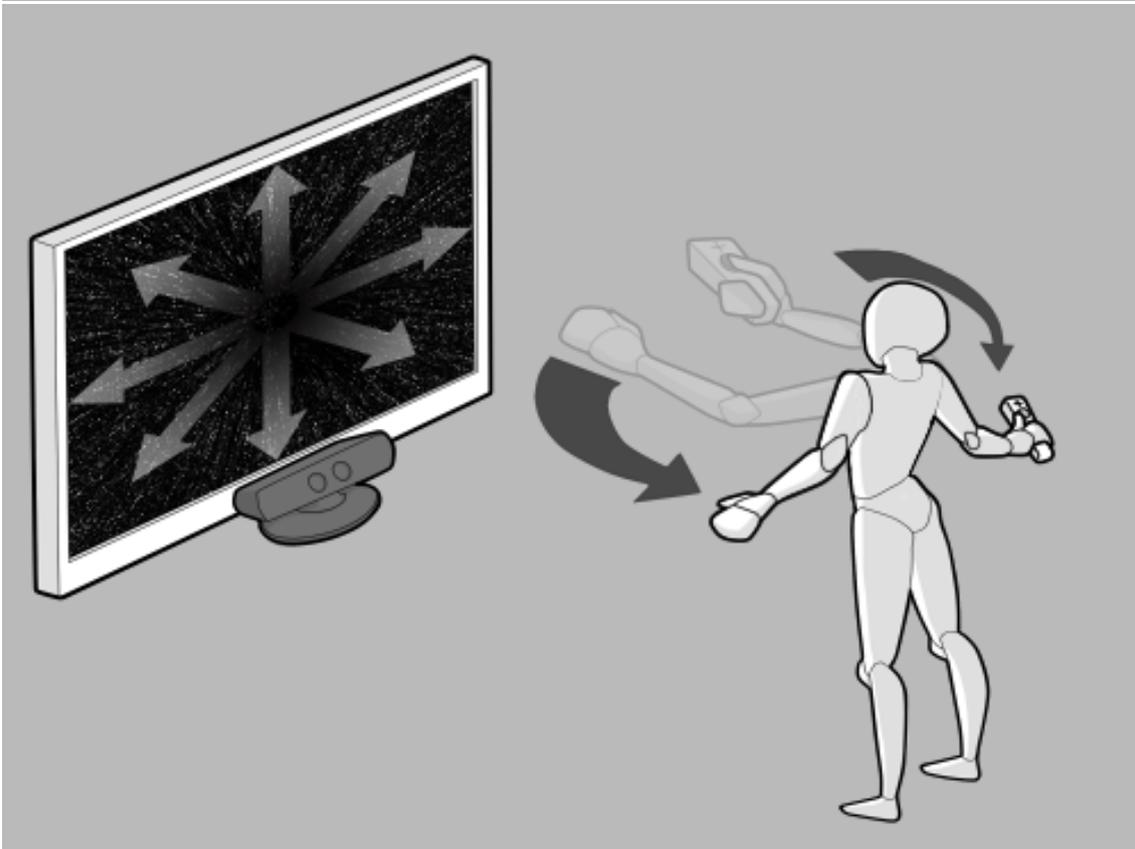
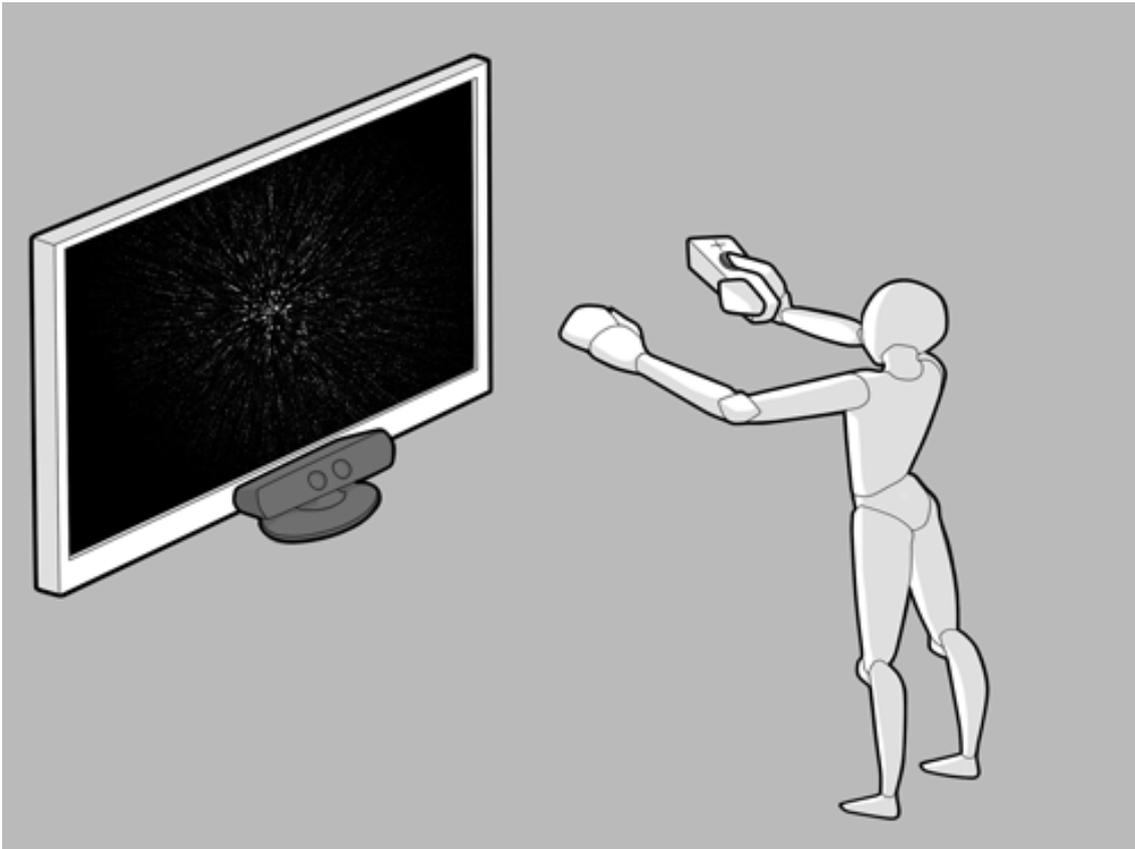


Figure 1. A schematic illustration of the Virtual swimming. Kinect (under the display) detected the movement of the observer's hands, shoulder and head and in accordance with those movement the expansional or contractional dots were presented.

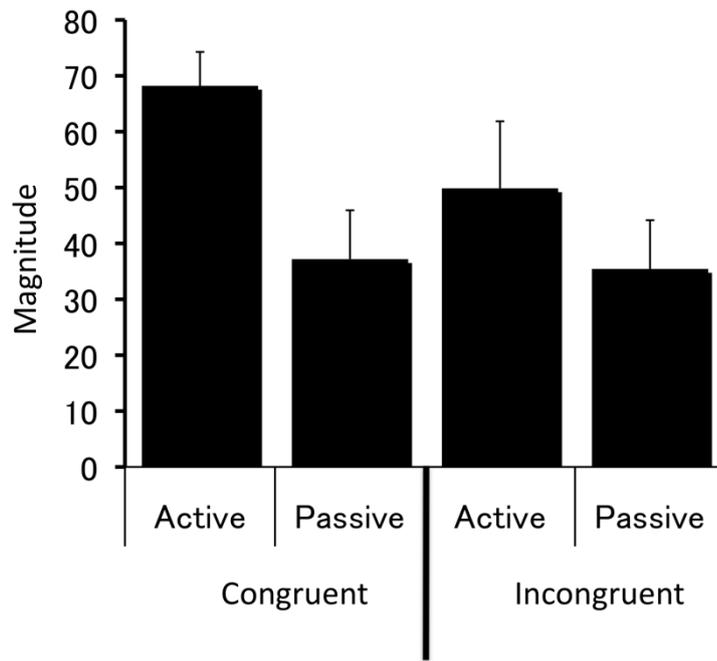
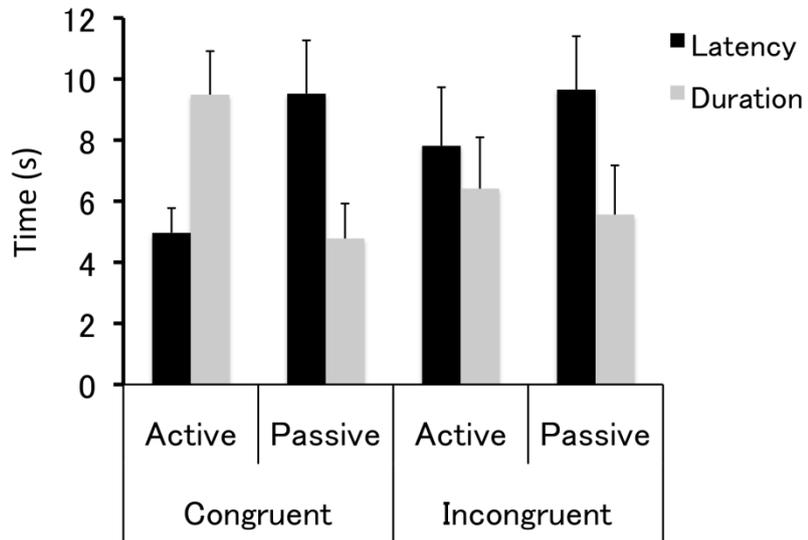


Figure 2. The results ofvection. The abscissa axis indicates four conditions. The error bars were SEs across subjects. The upper panel shows the results of latency and duration and the bottom shows the magnitude.

#### Acknowledgement

We thank Tomomi Ogura for her beautiful figural design. The first author (TS) was aided by Japan Society for Promotion of Science.

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